Shallow-Water Propagation

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LONG-TERM GOALS

Develop propagation models and methods for complex shallow-water environments, test their capabilities and accuracy, and apply them using environmental and acoustic data.

OBJECTIVES

(A) To handle range-dependent elastic and poro-elastic sediments, waveguides of variable overall thickness, and strong pulse and broadband sources.
(B) To determine field statistics efficiently from stochastic propagation models and to quantify effects of random environmental and experimental variability.

APPROACH

(A) High-order PE techniques, including energy conservation corrections and time-domain formulations, are applied to sediment equations that include anisotropy and nonlinear effects.
(B) Stochastic ensembles of geoacoustic and ocean variability are constructed using data samples and representations by empirical orthogonal functions.

- For both efforts principal collaborators are: Rensselaer graduate students; Dr. Michael Collins (NRL) for propagation model development; and Dr. Mohsen Badiey (Delaware), Dr. William Carey (NUWC), and Dr. James Lynch (WHOI) for modeling and analysis of experimental data.

WORK COMPLETED

(A) A PE model was derived [1] to handle depth and range variability of elastic sediments for which the geoacoustic properties are transversely isotropic (TI). An initial formulation was developed [2] for an extension using Biot theory to TI poro-elastic sediments. A hybrid model that combines normal mode and PE methods was produced [3] to treat three-dimensional propagation in shallow and coastal waveguides whose effective thickness can vary significantly. An energy conserving extension for such problems was obtained [4] using conformal mapping and a WKBJ approximation. A high-order time-domain PE model was constructed [5] for range-dependent propagation of pulses with relatively high source strength. A treatment was produced [6] to handle both strong sources and frequency-dependent sediment attenuation and dispersion by switching between time and frequency domains in the split-step calculations.
(B) An efficient modeling of random ensembles for stochastic propagation calculations was presented [7] using ocean sound speed variability for illustrations. Extension and application of the

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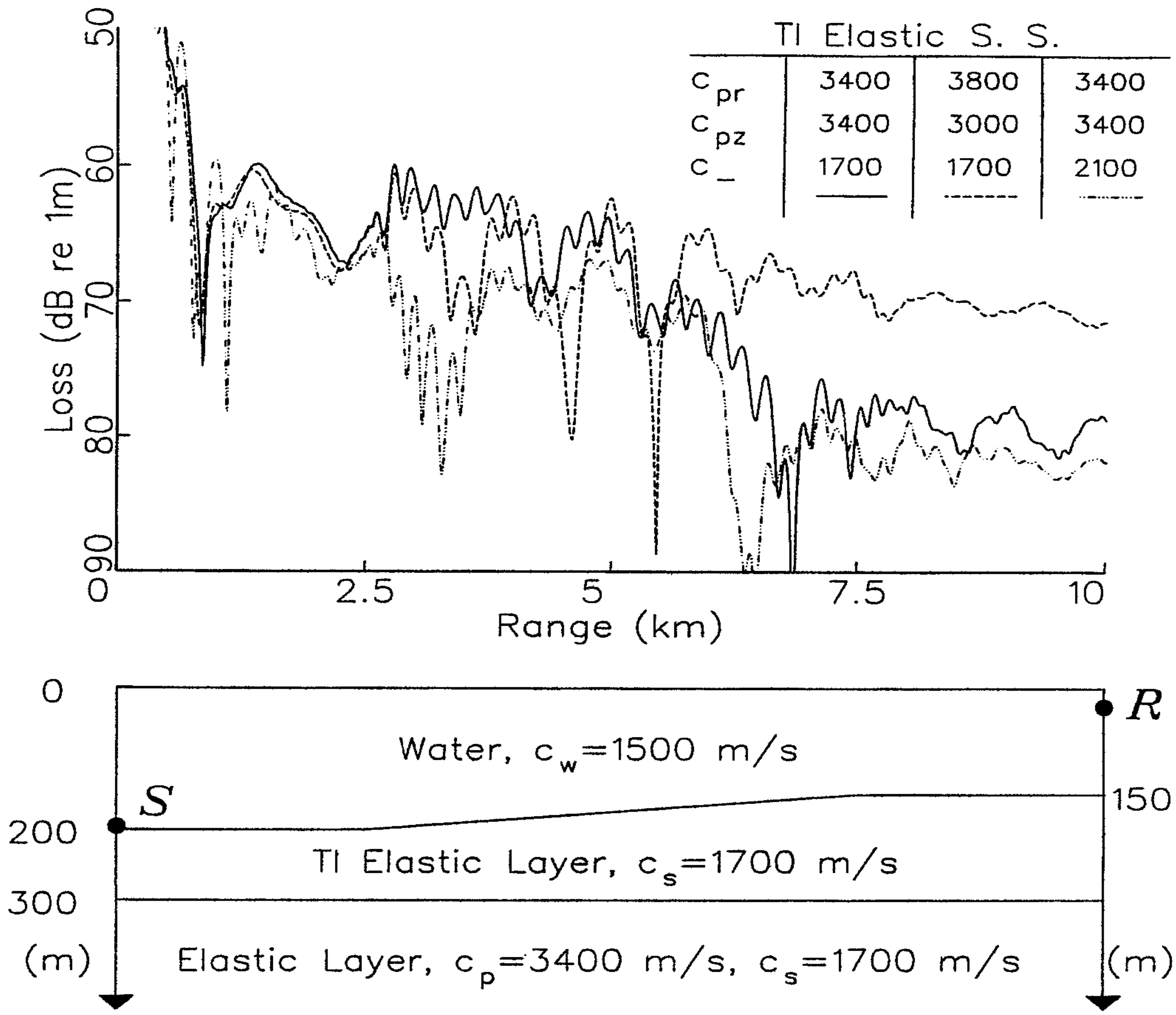
technique was developed [8] for random ensembles of sediment sound speed variability in the AGS region, and predictions of intensity statistics were calculated. Estimates were produced [9] of wave number statistics arising from fluctuations of sediment layer depths and sound speeds along several tracks of a 1995 AGS site experiment. Statistics of broadband intensity fluctuations were obtained and compared with data from eight tracks of a 1992 AGS site experiment [10]. Specific effects of small random fluctuations in the sediment volume and in layer interface heights were described on horizontal and vertical field coherences [11], using both a normal mode method and PE simulations.

RESULTS (from three selected investigations)

- Sediment anisotropy can arise in layer formation by deposition and also from the alignment of cracks and pores. Transversely isotropic sediments are natural to treat first, because isotropy in horizontal planes is typical for ocean bottoms and because the governing equations are easier to handle than those for full anisotropy. Nonetheless even for elastic TI sediments, we discovered that PE models required a new formulation [1] using different dependent variables from those in isotropic models. We found that this formulation, in combination with recent PE improvements including the split-step Pade′ implementation and a rotated branch cut (Milanazzo, Zala, and Brooke), permits construction of an efficient high-order algorithm. From several simulations we conclude that propagation modeling of TI sediments is feasible and that TI effects can influence transmission loss [Fig. 1].

- Strong source effects arise through nonlinear mechanisms and are usually treated by time-domain calculations. Sediment attenuation and dispersion are measured and modeled as functions of frequency, and time-domain treatment of them is inefficient. Our hybrid PE algorithm [6], which decomposes a broadband signal, marches frequency components while accounting for sediment properties, Fourier synthesizes, and corrects to account for nonlinearities, exploits the numerical splitting method (fractional steps) to handle the combined effects. We found that a major advantage of this procedure is its ease in incorporating improvements in PE models by updating the frequency-domain marching component. We conclude that the combined effects of sediment attenuation, dispersion, and source strength nonlinearities can be treated with a relatively efficient computational procedure, and that the individual mechanisms can affect the received pulses differently [Fig. 2].

- Statistics of broadband transmission loss fluctuations need to be determined efficiently in terms of uncertainties in oceanic, geoacoustic, and experimental variability. Small-scale geoacoustic variations are prevalent in sediment core profiles from the shallow-water AGS site, and we determined that randomly distributing the measured blow counts (while accounting for vertical correlation) could simulate realistic measurement uncertainties. We demonstrated [10] that each realization of geoacoustic profiles obtained from the cores could be interpolated efficiently by a procedure based on empirical orthogonal functions. Using PE simulations for both fluid and elastic sediments, we were able to obtain statistics for broadband propagation in range-dependent environments. We conclude that for the particular data examined very good agreement with frequency trends can be obtained, and that uncertainty levels in the geoacoustic environment and the experimental configuration limit modeling of detailed features of the data [Fig. 3].



<u>Fig. 1</u> ***[Lower] Slope-shelf environment for transmission loss simulations. Along with density 1.2 gm/cm^3 and attenuations 0.1 dB/λ, four sound speeds specify TI layer properties: the larger speeds for waves traveling in horizontal (c_{pr}) and vertical (c_{pz}) directions, the smaller speed (c_s) for waves in either horizontal or vertical directions, and the smaller speed (c_) in another direction (45 deg). [Upper] Transmission loss (f = 25 Hz, z_s = 195 m, z_r = 25 m) for isotropic sediment (solid curve) and for two types of TI layers. Faster horizontal sound speed (dashed curve) decreases energy conversion into the sediment, leading to shelf intensity about 10 dB higher than for isotropic case. For dot-dashed curve, intensity decrease occurs more rapidly over slope, resulting in a several dB drop over the shelf.***

IMPACT/APPLICATIONS

New and increased capabilities will be available for deterministic propagation predictions and data analyses. Efficient specification of intensity and coherence statistics arising from environmental

fluctuations and experimental variability will be feasible. Enhancements of inversion procedures will be produced.

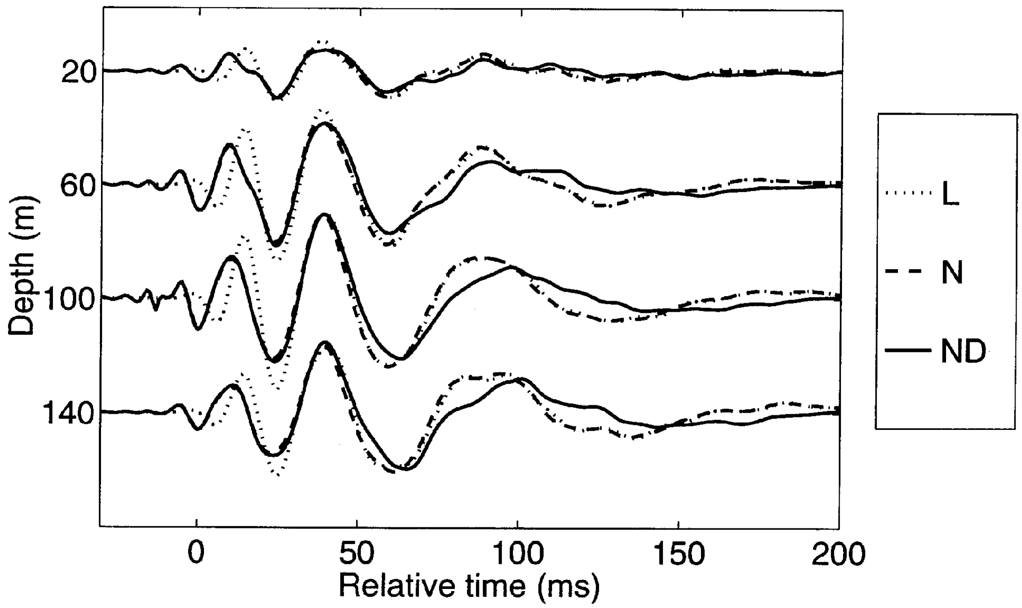


Fig. 2 ***Time-series pressure waveforms at four depths in an isospeed channel (depth 150 m, sound speed 1500 m/s) over a fluid sediment layer (depth 150 m, sound speed increasing from 1510 to 1610 m/s, density 1.5 gm/cm^3, attenuation 0.6 dB/λ and linearly increasing with frequency), from a Gaussian pulse source (bandwidth 132 Hz, depth 100 m). Pulse arrivals incorporating only nonlinearities (dashed curves) differ for later times from those including dispersion, attenuation, and nonlinearities (solid curves). Arrivals excluding these mechanisms (dotted curves) differ significantly for early times from solid curves. In this example, in contrast to some others, nonlinear and sediment mechanisms have roughly additive effects.***

TRANSITIONS

Propagation models and computer codes have been distributed. Results have been and are being used for modeling and comparisons with data from several series of experiments (HCE, AGS, ACT) that are partly directed toward sonar system improvements.

RELATED PROJECTS

- Additional research with Dr. Michael Collins (NRL) includes PE model improvements for energy conservation in elastic sediments [12], three-dimensional volume variability [13], and internal gravity and acoustic waves [14], along with an application to predicting the impact site of a large fragment from Comet SL-9 [15].

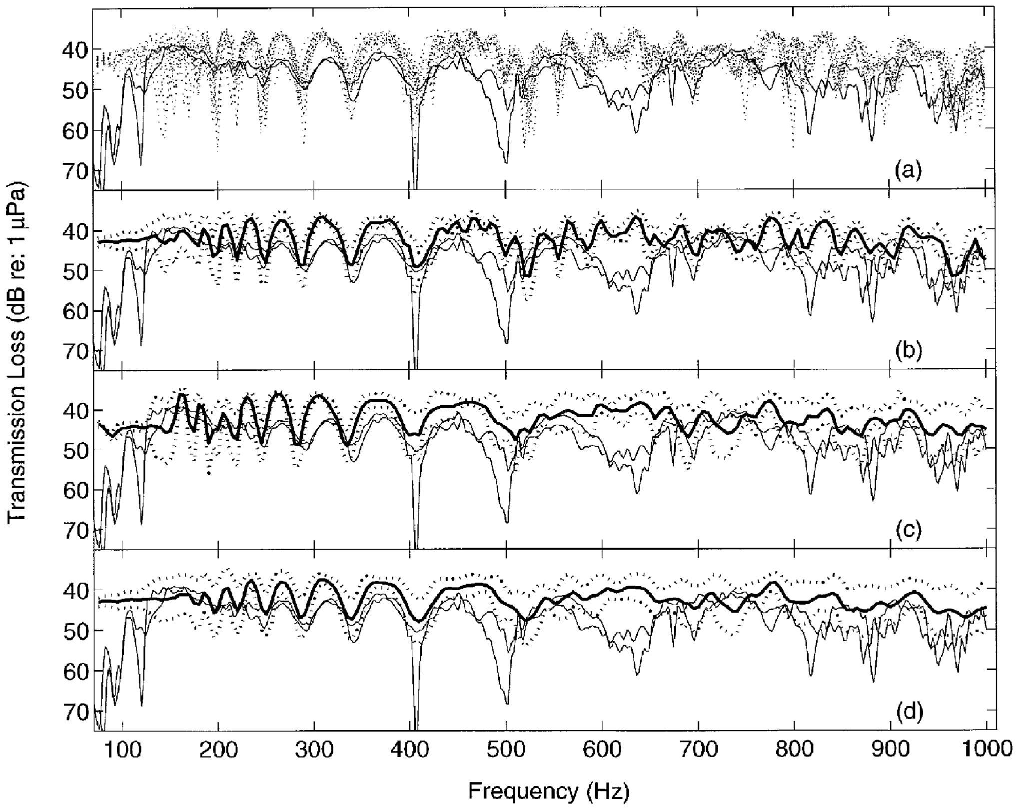


***Fig. 3** Thin solid curves are processed shot data (1992 AGS site Track 3, z_s = 5 m, z_r = 5 m) plotted with: (a) PE simulations (dotted) from 15 realizations of sediment sound speed variability with 1.5 m vertical correlation length; (b) mean (bold solid) of realizations in (a) and one-sigma bands (dotted) about the mean; (c) mean calculated within 15 m of plot range in (a) and one-sigma bands; (d) mean of all simulations in (a) calculated at all ranges in (c) and one-sigma bands. Results in (a) show similar trends of the data at low to mid frequencies; in (b) and (c) the means capture many features of the data and the one-sigma bands usually envelop the data; in (d) the mean levels generally follow the data except at intervals about 100 Hz and 650 Hz, and the wider one-sigma bands account for most but not all of the variability.*

- Ongoing work with Dr. Mohsen Badiey (Delaware) includes demonstration of three-dimensional coupling arising from sediment heterogeneity [16].

- Continuing work with Dr. William Carey (NUWC) and Dr. James Lynch (WHOI) includes determining effects of range dependence on coherence in shallow water waveguides [17].

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PUBLICATIONS

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